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This is a midterm report of the third year of BBN's ongoing effort in Knowledge Representation for Natural Language Understanding. BBN's ARPA project in this area is aimed at developing techniques for computer assistance to a decision maker in understanding a complex system or situation using natural language control of an intelligent graphics display. In this report, we give a brief overview of the objectives of the project, followed by a summary of recent progress.

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RESEARCH IN KNOWLEDGE REPRESENTATION FOR NATURAL LANGUAGE UNDERSTANDING

Semiannual Progress Report
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INTRODUCTION

This is a midterm report of the third year of BBN's ongoing effort in Knowledge Representation for Natural Language Understanding. Previous reports have been quarterly and have contained a brief technical summary of quarterly progress followed by one or more technical articles describing some aspect of the project. Starting with this report, we will be changing this practice so that technical articles will be issued as separate reports and semiannual progress reports will provide brief technical progress summaries. In this report, we give a brief overview of the objectives of the project followed by a summary of recent progress.

1. OVERVIEW

BBN's ARPA project in Knowledge Representation for Natural Language Understanding is aimed at developing techniques for computer assistance to a decision maker in understanding a complex system or situation using natural language control of an intelligent graphics display. The motivating need is that of a military commander in a command and control context both in strategic situation assessment and in more tactical situations - especially in crisis situations. In such situations, not only does the commander need certain information in order to make his decisions effectively, but in complex situations, this requires the presentation of that information in a form that is matched to the abilities of human comprehension.

1.1 The Need for Flexibility

The underlying assumption of this work is the following: in a crisis situation, the commander needs an extremely flexible system, capable of manipulating large amounts of data and presenting it on a graphical display in a variety of ways until the commander feels satisfied that he has a grasp of the situation. Such a system would have abilities to display many kinds of different map overlays, an ability to change the kinds and amounts of detail shown, an ability to conveniently construct

unique kinds of displays to suit the situation at hand, as well as the ability to display tabular and graphical information and present textual material in ways that are easily comprehensible.

In such circumstances, the display that the commander wants and the modifications to it that he will subsequently want must be described in a highly fluent and expressive language, at a level of abstraction appropriate to the commander's intent. That is, one must not require the equivalent of a graphics systems programmer in order to obtain the displays required. Rather, one needs a system that is capable of accepting an abstract specification of the essential details of what should be in a display, and then intelligently and effectively determining the remaining details necessary to actually produce that display. This is true whether or not the actual specification of requests to the computer system is done by the commander himself or by one or more subordinate specialists.

1.2 The Need for Fluency and Conceptual Power

If the language of such a system is to be matched well to human cognitive abilities, it appears necessary for it to include a number of aspects of ordinary natural language, such as the use of devices like pronouns and other anaphoric expressions, the ability to take an incomplete specification and fill in the

details on the basis of prior knowledge, and the ability to take a specification that would be potentially ambiguous out of context and determine the intended meaning. Although it might be possible to design an artificial language that met the above needs, we believe that the best methodology for developing such a capability is to use natural English as the communication language for such systems. Although natural English has the advantage of minimizing the problems of learning and remembering special conventions, it is important to understand that the primary advantages of English for this application are the way that the underlying conceptual structures of English can match the user's conceptualization of the problem.

1.3 The Need for Situationally Dependent Interpretation

The understanding of the commander's requests for information in the kinds of contexts that we envisage will require a number of capabilities that are significant research areas in knowledge representation and language understanding, many of which have not been adequately studied in the past. One of these is the need for situation dependent interpretation of linguistic devices such as deixis and anaphora. The mechanism of anaphora permits one to make a subsequent reference to something that has previously been said in a dialog (e.g., using pronouns or definite noun phrases to refer to previously mentioned

objects), deixis involves such references to things that have not been said, but are present in some way in the non-linguistic context of the conversation (e.g., in this case, what has just happened on the display screen). Anaphora has been extensively studied in linguistics (although the problems are far from solved), whereas deixis of the kind that occurs in the display context is considerably less well understood.

The resolution of both deictic and anaphoric reference requires the system to perform certain kinds of common sense inferences about the possible meanings of alternative possible referents, and the plausibility of those alternatives. This in turn requires an ability to store and use considerable amounts of knowledge about the domain of discourse and the goals and objectives of the user. In addition to these linguistic devices, there is another level of interpretation of the user's input that depends even more critically on the use of such knowledge. This is the filling in of details that the commander can be assumed to have intended but did not literally say.

1.4 The Need for Intelligent, Helpful Systems

Much of the time in communication with the system, the commander will not say literally exactly what he means, and there are good reasons not to require him to do so. The major reason

is that it is cognitively inefficient to be meticulously literal in one's communication (that's why computer programming is a time consuming and expensive activity). One of the major activities in programming a computer to do a complex task is the systematic specification of all of the details that would be left unsaid if one were instructing a human to carry out the same task. In the command and control situations that we are considering, we cannot afford to require this degree of literal specification of detail. Rather, the system must know enough about the objectives of the user that it can fill in details in reasonable ways, asking the user for clarification occasionally, but only when absolutely necessary.

Moreover, the system should be able to use its general knowledge and the knowledge in its data base to go beyond merely doing what was requested, to provide additional information that can be inferred to be relevant to the user's goal and not otherwise known to the user. For example, when the commander asks how many of his interdiction fighters are equipped with a particular kind of radar during a mission planning operation, the system should volunteer information about how many of those radars are out of commission (unless it knows that the commander already knows that). That is, the system should go beyond the passive execution of the user's commands to infer the goal structure underlying those commands where possible, and to

volunteer additional relevant information (usually in accordance to standing instructions as to what kinds of additional information should be offered in what situations).

1.5 The Need for Knowledge Representation Research

The above discussion illustrates the extent to which the representation and use of general world knowledge, knowledge of the domain, and knowledge of the goals and objectives of users are critical in the development of fluent communication and effective information display in the above context. Moreover, these problems are fundamental bottlenecks in a variety of other artificial intelligence applications. Consequently, a major portion of our effort in this project has been and will continue to be devoted to fundamental problems of knowledge representation and use.

The KL-ONE knowledge representation system that we have developed during this project [Brachman, et al., 1979] serves as the vehicle of this research. KL-ONE currently has an exceptionally good representation for the inheritance relations among structured concepts, including the correspondences between corresponding parts of their structures. It has been used for representing a variety of different kinds of information in our current system, and has proven to be well structured in many

respects. However, there are many subtleties of representation that are still undergoing active investigation as part of the knowledge representation effort and that require continued development.

1.6 The Problem of Situation Recognition

Fundamental to the above uses of knowledge (in understanding and appropriately responding to user requests) is a problem that we have called "situation recognition". That is, at various points the system is in a state where it needs to determine which of a large number of possible rules of action are satisfied by its current situation. The discovery of such rules can become a significant factor when the number of rules in the system becomes large. Consequently, the development of representational structures and special algorithms for making such inferences efficient is especially important.

The work that we have done on knowledge representation has been guided by this need, and we have developed several concepts that we hope will provide sufficient speed and efficiency fo making use of large knowledge bases. One of these is the view of KL-ONE networks and certain structures within them as instances of cascaded generalized transition networks [Woods, 1979] with advantages similar to those of ATN grammars.

1.7 The Need for Parallelism

In spite of the improvements in representational efficiency discussed above, it remains likely that the amount of processing required for intelligent, helpful systems of the kind that we envisage will require significant processing resources. The process of situation recognition, which is at the heart of much of this processing, is fundamentally a kind of search and carries an inherent risk for combinatoric cost. Hence, we have been exploring a class of algorithms for situation recognition and similar inferential operations that make use of highly parallel marker passing disciplines on abstract parallel machines. These algorithms have a potential for massive parallelism and hold significant promise for providing real time operation of intelligent knowledge-based systems when embodied in specialized VLSI computer systems.

1.8 The Experimental Prototype

In order to explore the knowledge representation and language understanding issues discussed above, we have implemented an experimental system that completes the cycle from user input in natural English to the generation of an image on a two-dimensional graphics display. For the sake of experimental convenience (so that the system designers can serve as genuine

users of the system), we have replaced the geographical maps of the commander with an isomorphic domain consisting of an ATN grammar laid out spatially on a surface. The user of this system can make requests for portions of the grammar to be di-· yed, for the window to be zoomed in or out, for specified states or arcs to be made visible or invisible, and can ask questions for details, some of which involve coordination of linguistic requests with pointing actions to objects on the display. The KL-ONE knowledge representation system is used at several points in this system - to represent a taxonomy of syntactic structures for organizing semantic interpretation rules, to maintain a taxonomy of speech acts for the speech act interpreter that determines user intent, and to represent the descriptions of the objects to be displayed and to organize the procedures that produce the display. This system is described in detail in [Brachman, et al., 1979].

1.9 Summary

In summary, the work that we have been doing falls into three classes, successively motivated by the initial goal of providing powerful computer assistance to a commander in a complex decision-making task. These areas are:

1. Fluent natural language understanding in a graphics context - including helpful systems that go beyond mere passive execution of literal instructions

2. Fundamental problems of knowledge representation and use, and

3. Abstract parallel algorithms for knowledge base inferential operations.

2. PROGRESS

The major accomplishment in this work during the previous two years has been the development of the knowledge representation system KL-ONE and its use in the construction of an experimental prototype system that understands English requests for display manipulation. This system parses and interprets English requests, synchronized with pointing events on a screen, and produces appropriate display actions on a bit map graphics display in response. It permits a user to request portions of a display to be shown, objects in the display to be made visible or invisible, attributes of objects pointed to to be displayed, and specification of refocusing requests by means of statements of constraints on what is to be visible.

The knowledge representation system KL-ONE is used in this system to organize the semantic interpretation rules used to interpret sentences, to organized the models of the user's goals and beliefs (which are used to fill in details that are not explicit in the input), and to organize the knowledge of displays and display forms that are used to draw the pictures on the screen. The knowledge structuring capabilities of the KL-ONE system have proven themselves very powerful in this system, and the extent to which the same structures have proven useful in qualitatively different parts of the system gives evidence of the robustness of these capabilities.

2.1 Improvements in KL-ONE

During the past six months, work has continued in a variety of directions. We have spent a considerable amount of time working with the overall language understanding system. Among other things, this work included a general speedup of the KL-ONE system; in particular, the attached procedure mechanism was improved substantially. Attached procedures have always been invoked at various places in various KL-ONE interpreter primitives by calls to LISP functions (#RunProcedures) that (1) look for any inherited procedures, and (2) invoke them appropriately. In a moderately complex operation on the network, quite a few searches could be invoked, even if no procedures were available.

In order to avoid this needless search, we had coded a function called #FindAllProcedures such that the result of a search would be stored after first invocation (in a saved-attached-procs list), and then directly used on subsequent access. To further improve the efficiency of this operation, we have made object-type specific versions of the attached procedure-finding procedures, so that no selection on type need be made (e.g., #RunRoleProcedures). Also, these functions have been converted to macros, thereby allowing them to be compiled in-line. Thus, function-calling overhead is avoided as well.

The net result of these improvements was that a typical display operation was speeded up by a factor of 6-10, and the parsing operation was speeded up by a factor of 2-3. The implemented mechanism is now just about as streamlined as we expect it to get. The next phase of work involves re-examination of the invocation situation taxonomy.

Another aspect of this period's work involved the design and coding of some new experimental functions. One set of these implements a crude separation between Concepts for fully-defined terms and Concepts for "natural kind terms" (NKT's) - i.e., whose KL-ONE definition is a set of necessity but not sufficiency conditions. For Concepts like TRIANGLE, it is sufficient to determine subsumption by A POLYGON WITH 3 SIDES in order to determine that something is definitely a triangle. On the other hand, descriptions like "human" may be suggested by "featherless biped", or whatever, but one can not conclude human-ness (i.e., subsumption by the Concept HUMAN) from just these conditions. There is always possibly "more to the story" - (whereas for triangles, there is no more to the story than "three-sided-polygon-ness").

Thus, our MSS algorithm, which given a concept description searches for the most specific concepts that subsume it, cannot conclude subsumption by NKT Concepts even though all appropriate

Roles are subsumed. Our first attempt to implement this distinction is simply to mark some Concepts as special ("magic"), so that MSS will not proceed "below" them. A Concept can be marked or unmarked as special, and whether or not it is an NKT will be printed when it is viewed. MSS has been altered to ignore apparent subsumption of NKT's when internal structures have been marked "magic". A CLISP iterative operator for enumerating only those subConcepts not specially marked has also been implemented. We will be experimenting with the ramifications of this new distinction.

Another set of experimental functions has been coded to help us investigate the distinction between different kinds of relationships felt to be "meta". In particular, the existing KL-ONE allows "meta-description" along the lines of [Smith, 1978] to express things like "THE KL-ONE-CONCEPT WHOSE NAME IS ATN-STATE". We have implemented functions to construct automatically things like "THE CONCEPT OF AN ATN-STATE" as an "abstract individual". Procedures for easily traversing from "intension" to "extension", as well as for printing these relationships, have been implemented.

Also during this period we have completely reorganized the KL-ONE implementation. In particular, the old system comprised a small number of very large files, which eventually became so

large that they could not be updated and recompiled easily (and sometimes not at all). Thus, we have taken the system and broken it into four levels of program: "system" code -- including basic definitions (records, data type declarations, etc.); "KL-ZERO" code -- this includes the primitive functions for manipulating the data types (network-building, changing, and searching primitives); "KL-ONE" code -- this implements the KL-ONE language as conceived in the abstract (it is a set of primitive functions for implementing each of the "epistemologically primitive" node and link types); "KLONEUSERS" code -- this is the set of accompanying utilities that make the system easier to use (including JARGON, printing, network saving and reloading, etc.).

Each part of the system has also been broken down into a set of conceptually clean modules. For example, KLZERO, which used to be one file with over 200 functions, is now a set of nine files, each encompassing one or two aspects of the system (e.g., Concept functions, Role functions, RSR functions). This makes editing and compiling extremely easy (and much faster). Each of the files has a maintained MASTERSCOPE database, to make examining the system code easier.

2.2 Theoretical Investigations

Considerable effort has been spent during the last six months on the theoretical foundations of the KL-ONE epistemology and on the approach to speech act interpretation used in the system. The former work has focused both on making clear and consistent extensions to KL-ONE's representational capacities, and on reaching a deeper understanding of its current capabilities. In the course of this work, we have been striving for a consistent and extensible semantics for KL-ONE with an eye toward realizing in KL-ONE a higher order modal system able to represent both its own syntax and at least some part of its own semantics.

We have been working on a reinterpretation of KL-ONE, with an eye turned most especially towards the problems of representing the content of assertions; more particularly of representing those aspects of content which are not a function of purely definitional relationships among concepts. This has involved trying to "semantically decompose" the SuperConcept cable so as more cleanly to allow the expression of non-definitional relationships among concepts (and their instances); and to separate out those conceptual connections which are grounded purely in semantical relations between concepts and those that, even if they hold in all possible

worlds, are necessary matters of fact. The semantic analysis of the SuperConcept cables entails a similar decomposition of the role link. Again, we are trying to rethink KL-ONE so that we can distinguish those cases in which a concept's having a certain role is definitional with respect to that concept, from those cases in which the role is not semantically linked to its source. This work is still quite new and its further development will almost surely involve other changes in our canonical interpretation of KL-ONE structures, especially those in which the mechanisms of contexts and nexuses are implicated.

In addition, during this period SIGART Newsletter #70 (February 1980) was completed and published. This was a special issue on Knowledge Representation that had taken a full year in preparation and is a significant contribution to the entire field of Knowledge Representation. It was authored by Ronald J. Brachman and Brian C. Smith.

In the area of speech act interpretation, we have begun the analysis of the speech act interpretation component of the current system leading toward a second generation redesign of this component. In this regard, there are two crucial issues. First is the question of the extent to which the audience must be supposed to be able to infer the speaker's non-linguistic plans. The present program makes use of techniques that are applicable

in cases where the system is able to strongly infer the user's plans. However, in many situations that we would like to be able to handle, it will not be possible for the system to achieve this level of understanding of the user's plans. Hence, we have been attempting to develop a framework in which a lesser degree of mutual belief is required on the part of the system. This in turn requires a greater capability for tracking the non-shared beliefs of the conversational participants.

Also in the area of speech act interpretation, we have been looking for more adequate analyses and representations for the concepts of acts in general. Questions that arise here have to do with the kinds of specifications of an act-type's preconditions and body. We have just started looking at these problems and they are, happily, independent enough from the above speech-act problems that we can make progress on the former without having had either to wait on or unwittingly constrain the progress of the latter.

Another area of research centers on extensions to the system's reference component. We have devised a machine for tracking discourse focus, and coded it in preparation for use in interpretation of referring and anaphoric expressions. This machine has a simple finite state behavior and will retain and move the focus of the discourse during sentence processing. We

have also prepared a paper on the focus machine and its use in discourse, which has been submitted to the "Discourse Processes" journal for publication. Also, we have begun doing research on the use of reference in discourses where information is visually present to the speaker and hearer. We are studying what assumptions speakers seem to be making about the hearer's ability to understand reference when both linguistic and visual contexts are present. An extended abstract of paper submitted for presentation at annual ACL meeting. As part of this effort, we have completed the design of an experiment to gather protocols of user behavior in simulated discourses involving visual display.

Finally, we have continued to pursue concepts of parallel inference algorithms for situation recognition in a taxonomic lattice. In January, two members of the project participated in an in-house course in VLSI design with the objective of improving our understanding of possible physical realizations of the kinds of parallel algorithms that we have been exploring. As a result of this course, some ideas for coordination between concurrent active processes in knowledge-based inference have been emerging. We will have more to say about this in our next report.

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